

Soil Nitrogen Dynamics Under Adjacent Native Forest and Hoop Pine Plantations of subtropical Queensland, Australia

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1. Abstract

Land-use change can impact soil nitrogen (N) dynamics and therefore the long-term maintenance of soil N cycling and availability. In this study, a series of laboratory experiments were undertaken to examine the influence of land-use change from a native forest (NF) to a first rotation (1R) and subsequent second rotation (2R) hoop pine (*Araucaria cunninghamii*) plantation on soil N dynamics. The impact of residue management on soil N dynamics was also investigated in the 2R forest, where soil N dynamics was measured in tree rows (2R-T) and windrows (2R-W). Results indicated that the land-use change from NF to 1R hoop pine plantation significantly reduced soil total carbon (C), total N, mineral N, soluble organic N (SON), gross nitrification, microbial biomass carbon (MBC) and respiration rate. Furthermore, the land-use change appeared to have a significant impact of microbial community composition measured using both BiologTM and MicroRespTM profiles. Land-use change from 1R to 2R hoop pine plantation resulted in a decline in TC, SON and microbial biomass N (MBN). It also resulted in an increase in gross ammonification and a change in microbial community composition. When compared to the 2R-T soils, the 2R-W soils tended to have a greater microbial biomass and respiration rate, and a larger SON pool. Residue management also influenced the microbial community composition measured in the MicroRespTM profiles.

2. Introduction

As a result of growing demands for forest products and a reduced forest land base, single-species plantation forests have become the dominant source of inputs for the Queensland forest industry. Almost a quarter (50,000 ha) of the Queensland plantation estate is accounted for by plantations of the nitrogen (N) demanding species, hoop pine (*Araucaria cunninghamii*) (QDPI&F, 2006). The majority of the hoop pine estate was originally native forest, and is currently moving into the second rotation phase. The future of plantations of this N demanding species is dependent on the long-term maintenance of soil N cycling and availability (Burton et al., 2007a). Soil N transformations are microbially mediated processes, and are influenced by a number of factors, including size, activity, composition and diversity of the soil microbial community, quality and quantity of organic matter input, and environmental conditions (Stevenson and Cole, 1999; Compton and Boone, 2002; Templer et al., 2003; Grenon et al., 2004). These factors are in turn influenced by land-use change and residue management (Tan et al., 2005; Ste-Marie and Houle, 2006; Burton et al. 2007a,b).

There is currently limited knowledge of how the land-use change from native forest (NF) to first rotation (1R) hoop pine plantation and subsequent second rotation (2R) hoop pine plantation, and the associated disturbance due to site preparation have influenced soil N transformations and availability. The objectives of this study were to examine the impact of land-use change from 1) NF to 1R hoop pine plantation, and 2) 1R hoop pine plantation to 2R hoop pine plantation on soil N dynamics. The impact of the current 2R residue management strategy was also examined. The key factors associated with land-use change and residue management that were considered to influence soil N dynamics were: alteration of tree species diversity, disturbance to the soil system, and differences in substrate quantity.

3. Methods

The study site is located in Yarraman State Forest, southeast Queensland, Australia (26° 52' S, 151° 51' E). Details of the study area were provided by Chen et al. (2004). In brief, annual rainfall at the site ranges between 433 and 1110 mm, with an average of 816 mm. The soil is a freely draining, Snuffy (Acidic) Mesotrophic Red Ferrosol (Isbell, 1996), equating to a Typic Durustalf (Soil Survey Staff, 1999), with a clayey texture (Chen et al., 2004). The NF site is classified as a mixed rainforest/scrub and is dominated by bunya pine (*Araucaria bidwillii* Hook.), yellowwood (*Terminalia oblongata* F. Muell. Subsp. *Oblongata*), crows ash (*Pentaceras australis* R.B) and lignum-vitae (*Premna lignum-vitae*), with emergent hoop pine (*Araucaria cunninghamii*). Experimental sites measuring 0.2 ha in area were located in adjacent NF, 1R hoop pine plantation (53 yr-old) and 2R hoop pine plantation (5 yr-old). Both the 1R and 2R hoop pine plantation sites were converted from NF in 1952. The first rotation of hoop pine at the 2R site was clearfall harvested in 1999 and post harvest residues were formed into windrows approximately 6m apart. The areas between windrows were cultivated and used as tree-planting rows for the 2R hoop pine plantation, which was established in

November 2000 at approximately 620 stems ha⁻¹. The 2R plantation was divided into two treatments based on the residue management practices. These were (1) tree-planting row (2R-T) and (2) windrow of harvest residues (2R-W). A buffer area of at least 50 m was left between experimental areas to avoid edge effects. Each of the four treatments (NF, 1R, 2R-T and 2R-W), had five 24 m² (12 m x 2 m) replicate plots. In July 2005, fifteen soil cores were randomly collected from the 0-10 cm layer of each of the five 24 m² plots within the NF, 1R, 2R tree row (2R-T) and 2R windrow (2R-W) forests using a 7.5 cm diameter auger and bulked. All samples were transported to the laboratory where field moist soils were well mixed and sieved (< 2 mm) and visible roots were removed. Samples were stored at 4 °C until the analysis could be conducted.

A sub-sample of each soil was air-dried at room temperature and soil total C and N were analysed using an isotope ratio mass spectrometer with a Eurovector Elemental Analyser (Isoprime-EuroEA 3000, Milan, Italy). Gross ammonification and mineralisation, and mineral N were determined using the methods described in Burton et al. (2007a). Soluble organic nitrogen and carbon were determined using the hot water extraction method described in Burton et al. (2007b). Microbial biomass C and N were measured using the fumigation-extraction method described by Vance et al. (1987) and soil respiration was measured using the method described by Chen et al. (2000). One-way ANOVAs were carried out on data for all parameters and least significant difference (LSD, P<0.05) was used to separate treatment means when differences were significant. The assumptions of normality and equal variance were satisfied prior to this analysis being conducted in SAS version 9.1.3.

Carbon source utilisation patterns, often referred to as community level physiological profiles or community level physiological profiling (CLPP), were assessed using both BiologTM and whole soil MicroRespTM techniques. BiologTM profiles were obtained using the method described by Widmer et al. (2001). Prior to multivariate analysis, individual well absorbance values were normalised by AWCD to account for possible differences in inoculation densities between samples (Garland and Mills, 1991). The MicroRespTM colourimetric detection plates were prepared and profiles obtained according to Campbell et al. (2003). Basal respiration (for water) and substrate induced respiration (SIR) (for individual C substrates) was calculated as CO₂-C evolved according to Campbell et al. (2003). For each plate, the average amount of CO₂-C that evolved per sample was calculated and used to normalise individual well responses before multivariate analysis was conducted. Cluster analysis using Bray-Curtis as the distance measure with graphical representations based on complete linkage for the hierarchical clustering was carried out on normalised data from the BiologTM and MicroRespTM profiles in the statistical package R version 2.4.0.

4. Results and Discussion

A laboratory incubation using the ¹⁵N isotope dilution method was undertaken in order to examine the impact of land-use change and residue management on gross N transformations (Burton et al. 2007a). Results showed that land-use change had a significant impact on soil N transformations (Table 1). The conversion of the NF to the 1R hoop pine plantation significantly reduced the availability of NH₄⁺-N and NO₃⁻-N, and decreased the rate of gross nitrification (Table 1). This result was related to lower soil, litter and root C:N ratios in the NF compared to the 1R hoop pine plantation (Burton et al., 2007a), indicating a reduction in organic matter quality associated with the land-use change. The conversion of 1R to 2R hoop pine plantation resulted in an increase in the gross rate of ammonification (Table 1). This was attributed to an increase in mineralisation of native organic N associated with changes in soil physical conditions and microclimate as a result of harvesting. Residue management was found to have no significant influence on the soil N transformations in the 2R plantation approximately five years after establishment.

A second study focused on quantifying the impact of land use and residue management on soil soluble organic N (SON) pools using a variety of extraction methods, including water, hot water, 0.5 M K₂SO₄, 2 M KCl and hot KCl (results of the hot water extractable pool only are shown in Table 1. All results can be found in Burton et al. 2007b). Both land use and residue management were found to have a significant influence on the size of soil SON pools. The conversion of NF to 1R hoop pine plantation tended to result in a decrease in the amount of soil SON (Table 1). This reduction coincided with increased soil, litter and root C:N ratios, and may therefore be the result of a decline in organic matter quality and quantity. The conversion of 1R to 2R hoop pine plantation generally resulted in a reduction in the amount of SON (Table 1). Residue management also influenced soil SON pools, which tended to be higher in windrows of harvest residues than in tree rows.

The impact of land-use change on the size, activity, and composition of the soil microbial community was examined using fumigation-extraction, CO₂ respiration, and community level physiological profiling (CLPP) techniques. Land-use change from NF to 1R hoop pine plantation resulted in a reduction in microbial biomass and activity, and a shift in soil microbial community composition (Table 1 and Figure 1). While the conversion from 1R to 2R hoop pine plantation appeared to have no significant influence on the size and activity of the soil microbial community, there were some indications of a difference in community composition (Figure 1). Soil microbial biomass and activity tended to increase as the quality and quantity of organic matter input increased.

Table 1 Chemical, biochemical and biological properties of the 0-10 cm layer soils in the adjacent native forest (NF), 53 y-old first rotation hoop pine plantation (1R), 5 y-old second rotation tree row (2R-T), and second rotation windrow (2R-W) at the Yarraman site, subtropical Australia. Values are means (n=5) and if followed by the same letter are not significant at the 5% level of significance

	Forest Type			
	NF	1R	2R-T	2R-W
TC	8.9a	7.1b	5.8c	6.1c
%				
TN	0.75a	0.52b	0.46b	0.47b
%				
C:N	11.8c	13.7a	12.6b	12.9b
ratio				
NH ₄ ⁺	2.5a	2.1b	2.1b	2.2b
(mg N kg ⁻¹)				
NO ₃ ⁻	98.6a	43.8b	43.1b	58.5b
(mg N kg ⁻¹)				
Gross	0.74b	0.62b	1.78a	1.50a
ammonification				
(mg N kg ⁻¹ d ⁻¹)				
Gross	6.6a	2.1b	2.5b	2.6b
nitrification				
(mg N kg ⁻¹ d ⁻¹)				
SON	160a	81b	60c	77bc
(mg kg ⁻¹)				
SOC	1628a	1053b	714c	1025b
(mg kg ⁻¹)				
MBC	2156a	1365b	1186b	1353b
µg g ⁻¹				
MBN	231a	188ab	130c	156bc
µg g ⁻¹				
Average	1.12a	0.81b	0.78b	0.90b
respiration rate				
(CO ₂ -C g ⁻¹ h ⁻¹)				

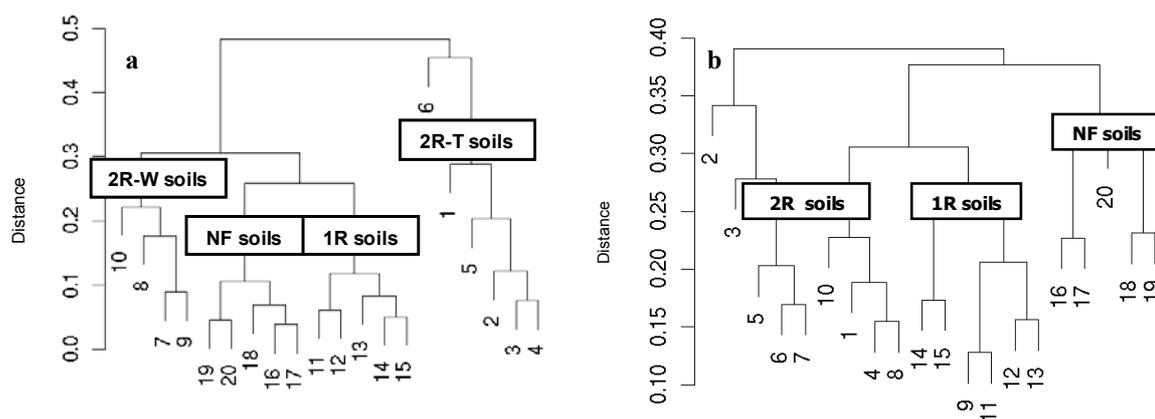


Figure 1 Cluster analysis of (a) MicroResp™ profiles of the 0-10 cm soil layer and (b) Biolog™ profiles of the soil extracts from the 0-10 cm soil layer of the adjacent native forest (NF) (numbers 16-20), 53 y-old first rotation hoop pine plantation (1R) (numbers 11-15), 5 y-old second rotation tree row (2R-T) (numbers 1-5), and second rotation windrow (2R-W) (numbers 6-10), at incubation time of 6 h. Scale indicates Bray-Curtis distance with graphical representations based on complete linkage for the hierarchical clustering

From these results, it was concluded that land-use change and to a lesser degree, residue management, had a significant impact on soil N dynamics. This was possibly associated with shifts in the quality and quantity of organic inputs, soil microbial properties and microclimate conditions. Results from this study indicate that land-use change and residue management may have implications for the long-term productivity of the soil resource. Future studies are required to improve the understanding of the chemical and biological mechanisms driving changes in soil N dynamics.

5. References

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